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By W. Sottorf

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According to the Froude method of testing with models, the resistance of a full-scale craft is determined from the formula

$$W = \underbrace{(w}_{\mathrm{I}} - \underbrace{c_m\, f'\, \frac{\rho}{2}\, v^2}_{\mathrm{II}})\ \lambda^3 + \underbrace{c_s\, F'\, \frac{\rho}{2}\, V^2}_{\mathrm{III}}\ **$$

in which the term I represents the total resistance of the model; and term II, the frictional resistance of the model; and term III, the frictional resistance of the full-scale craft. The frictional resistances II and III are calculated in the evaluation of the towing tests of ship models with the aid of the empirically determined frictional coefficients c_m and c_s, whereby it is assumed that the nature of the flow is the same with the model and with the full-scale float as with the flat surfaces used for determining the frictional coefficients. It is also assumed that the wetted surfaces f' and F' are the same in motion as at rest and that the local speed variations, which occur on a ship in contrast with a flat surface of almost zero displacement, are negligible in their mean value in comparison with the model and ship speeds used in the formulas.

The great conversion accuracy of ship-model tests, which average about ±2 per cent of the power and ±1 per cent of the propeller revolution speeds, shows that in

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*"Ueber den Einfluss des Modellmassstabes bei der Untersuchung von Flugzeugschwimmern." Z.F.M., December 28, 1932, pp. 713-719.

**W, w, total resistances of full-scale craft and of model.
F', f', wetted surfaces of full-scale craft and of model.
V, v, speeds in meters per second of full-scale craft and of model.
c_s, c_m, coefficients of friction of full-scale craft and of model.
λ, scale of model.

such tests these simplifying assumptions in the conversion formula are permissible.

In the conversion of the towing results of planing water craft, i.e., seaplane floats and planing boats, the use of the above-mentioned conversion method is complicated and impossible in practice:

Because the wetted surface varies with the speed and with the angle of trim at the same speed, so that the conversion would have to be made separately for every test point, for which the wetted surface would always have to be measured;

Because the mean velocity of the water along the planing surface differs considerably from the towing speed, as has been shown by pressure tests (reference 1), so that the introduction of the towing speed into the conversion formula would lead to errors;

Because the determination of the frictional coefficients for the model is unreliable, since, with small model scales, the frictional coefficients occur as functions of Reynolds Number in a region where, for the same values of R, they may have different values, according to which boundary-layer condition occurs as a result of the conditions of approach.

I. SCALE TESTS WITH GLIDING SURFACES

For the purpose of solving all the problems involved, an investigation was made in the H.S.V.A. (Hamburgische Schiffbau Versuchsanstalt) with flat, rectangular planing surfaces. These experiments represent part of a comprehensive program, the first results of which were reported in Werft-Reederei-Hafen, November 7, 1929. (See reference 1.)

The investigation of a flat, rectangular planing surface, which can be considered as the portion of a flat float bottom lying in front of the step, has the advantage that the frictional resistance can be determined directly from the test results. Normal and tangential forces act on the lower side of the planing surface towed through still water, while the upper side and the lateral edges are under constant atmospheric pressure. Here it is assumed that a separation of the water has occurred at the edges of the surface, whereby the pure gliding condition is defined. According to Figure 1, with the assumption of a nonviscous fluid (case a), as a result of which the tangential or frictional forces disappear, the attainable minimum of the resistance is

$$W = A \tan \alpha.$$

In a viscous fluid with an additional frictional force T we have

$$W = A \tan \alpha + \frac{T}{\cos \alpha},$$

if A has been experimentally found to be constant. The horizontal component of the frictional resistance is therefore

$$W_R = W_{tot} - A \tan \alpha,$$

and the frictional resistance in the direction of the surface is

$$T = W_R \cos \alpha.$$

For the determination of the frictional coefficient $c_f = \dfrac{T}{F' \frac{\rho}{2} v_m^2}$ it is also necessary to measure the wetted surface F'. For this purpose a strip of glass is set into the planing surface at one-fourth of the width, through which the mean length l' of the wetted surface is read on a scale during the test.

For the determination of the mean speed v_m, the lower speed $v_u = f(\alpha)$, obtained from the pressure measurements in the above-mentioned work and given in the table of test results, was used.

Experimental Program

The basis was the experiment with the planing surface A having the width $b_1 = 0.3$ m (0.98 ft.), here numbered 2, from the above-mentioned work, and particularly the test at $v = 6$ m/s (19.68 ft./sec.) with 18 kg (39.68 lb.) load. According to Froude's law, we obtain for a similar planing surface of the width b_2, i.e., the scale $\lambda = b_2/b_1$, the corresponding speed $v_2 = \sqrt{\lambda}\, v_1$ for a similar load $A_2 = \lambda^3 A_1$. The test program for the six planing surfaces investigated is accordingly as follows:

Surface	b m	v m/s	A kg
1	0.600	8.48	144.000
2	0.300	6.00	18.000
3	0.225	5.20	7.600
4	0.150	4.24	2.250
5	0.100	3.46	0.660
6	0.075	3.00	0.281

The planing surfaces were towed with the constant load A at constant speed v and variable moments M, and the resistance, angle of trim and wetted length were measured.

Apparatus

The set-up (fig. 2) is the same in principle for all planing surfaces, except that, with the great range in the loads from A = 281 g (0.62 lb.) for the smallest area to A = 144 kg (317 lb.) for the maximum area, changes had to be made in each case to correspond to the required accuracy. The surface was suspended by two vertical wires which passed over pulleys to the counterweights, by the mutual shifting of which the moment and consequently the angle of trim could be changed. The forward end of the planing surface was attached to a wire which led to the dynamometer. The dynamometer spring was calibrated by means of a wire extending aft from the same point, whereby allowances were made for all the influences resulting from any slight displacement out of line of the planing surface during the test. For the sake of greater accuracy in measuring the small forces of surfaces 5 and 6, the dynamometer was disconnected and the measurement was made as a pendulum measurement with the aid of a very weak spring. The planing surfaces lay behind a windshield, so that the results were not affected by the relative wind.

Results

In Figure 3 the nondimensional value $\epsilon = W/A$ is plotted against α for all the surfaces tested. It is obvious at once that all the test points can be connected, with very little scattering, by curves in which the planing number ϵ grows more unfavorable, the smaller the scale selected. It is especially noteworthy that the transition, from the condition in which the lateral edges are not yet free from the water to the pure planing condition, occurs at a so much greater angle of attack the smaller the scale is, as is shown by the plotted limiting curve. This establishes a lack of similarity in the form of flow at too small scales. Figure 4 shows, in the curves I, II, and III, the region of Reynolds Numbers in which the frictional coefficients c_f may differ considerably from one another, according to whether the developing boundary layer has a laminar or turbulent character, or is turbulent with laminar approach.

Results of Tests with Planing Surfaces

Test No.	α		$\frac{F'}{b^2}$	$\epsilon = \frac{W}{A}$	$\frac{M^*}{A\ b}$	N_R	c_f
Surface 1; $b = 0.6$ m; $A = 144$ kg, $v = 8.48$ m/s							
	deg.	min.					
1	4	46	2.318	0.1403	1.430	8.75×10^6	0.00279
2	5	8	1.816	0.1403	1.373	7.67×10^6	0.00287
3	5	34	1.733	0.1410	1.194	6.62×10^6	0.00285
4	5	34	1.766	0.1403	1.122	6.62×10^6	0.00280
5	6	5	1.360	0.1410	1.000	5.45×10^6	0.00285
6	6	52	1.167	0.1438	-	- -	-
Surface 2; $b = 0.3$ m; $A = 18$ kg; $v = 6$ m/s							
	deg.	min.					
7	2	36	4.670	0.1845	2.660	6.41×10^6	0.00327
8	3	47	3.050	0.1600	2.145	4.22×10^6	0.00333
9	3	58	2.918	0.1566	2.060	3.98×10^6	0.00333
10	4	10	2.700	0.1567	2.015	3.68×10^6	0.00348
11	4	15	2.600	0.1540	1.840	3.56×10^6	0.00339
12	4	26	2.395	0.1508	1.760	3.26×10^6	0.00343
13	5	8	1.935	0.1442	1.171	2.63×10^6	0.00317
14	5	12	1.885	0.1470	1.416	2.545×10^6	0.00338
15	5	31	1.717	0.1460	1.308	2.28×10^6	0.00332
16	5	40	1.634	0.1460	1.215	2.16×10^6	0.00339
17	6	53	1.060	0.1505	0.836	1.41×10^6	0.00331
18	7		1.000	0.1505	0.765	1.315×10^6	0.00334
19	7	54	0.783	0.1595	0.570	1.000×10^6	0.00331
20	8	58	0.606	0.1695	0.450	-	-
21	9	34	0.544	0.1760	0.405	-	-

*See footnote, page 6.

Results of Tests with Planing Surfaces (cont'd)

Test No.	α deg.	α min.	$\frac{F'}{b^2}$	$\frac{W}{A}$	$\frac{M^*}{A\ b}$	R	c_f
Surface 3; b = 0.225 m; A = 7.6 kg; v = 5.2 m/s							
22	3	27	3.450	0.1710	2.313	3.07×10^6	0.00355
23	4		2.850	0.1622	1.995	2.52×10^6	0.00362
24	4	57	2.010	0.1520	1.355	1.762×10^6	0.00368
25	5	37	1.560	0.1486	1.090	1.360×10^6	0.00372
26	6	41	1.110	0.1520	0.828	0.955×10^6	0.00374
26a	6	40	1.110	0.1520	0.828	0.955×10^6	0.00374
							8% roughened
26b	6	38	1.125	0.1560	0.828	-	0.00420
							16% roughened
26c	6	38	1.145	0.1683	0.828	-	0.00541
							32% roughened
27	7	48	0.822	0.1613	0.580	0.690×10^6	0.00371
Surface 4; b = 0.15 m; A = 2.25 kg; v = 4.24 m/s							
28	2	59	3.500	0.2000	2.380	-	-
29	4	19	2.467	0.1720	1.817	1.19×10^6	0.00439
30	4	43	2.053	0.1645	1.534	9.86×10^5	0.00452
31	5	30	1.698	0.1623	1.288	8.10×10^5	0.00445
32	6	12	1.350	0.1578	0.993	6.37×10^5	0.00427
33	8		0.787	0.1662	0.504	3.57×10^5	0.00411
Surface 5; b = 0.1 m; A = 0.660 kg; v = 3.46 m/s							
34	2	53	3.900	0.2820	2.135	-	-
35	4	25	2.600	0.2258	1.755	6.82×10^5	0.00634
36	5	4	2.150	0.2000	1.565	5.59×10^5	0.00584
37	5	29	1.820	0.1880	1.255	4.71×10^5	0.00575
38	5	56	1.500	0.1788	0.952	3.97×10^5	0.00574
39	7	8	1.000	0.1726	0.640	2.51×10^5	0.00573
40	8		0.750	0.1803	0.444	1.85×10^5	0.00661
Surface 6; b = 0.075 m; A = 0.281 kg; v = 3 m/s							
41	2	59	3.860	0.3220	2.300	6.63×10^5	0.00768
42	3	42	3.200	0.2825	2.155	5.42×10^5	0.00757
43	4	50	2.200	0.2360	1.450	3.82×10^5	0.00760
44	6		1.535	0.2110	1.040	2.56×10^5	0.00806
45	7	9	1.000	0.1850	0.480	1.76×10^5	0.00675
46	8	6	0.868	0.1911	0.414	1.40×10^5	0.00718
47	9	32	0.667	0.2100	0.283	1.03×10^5	0.00872

*The reference point for the moments is the trailing edge of the gliding surface.

Mean velocity on lower side of planing surface

$$v_n = v - v_m$$

α	2°	4°	6°	8°	10°
v_n in %	0.4	1.3	3.4	7.2	13.2

If we introduce into this diagram the friction coefficients determined from the tests

$$c_f = \frac{W_R \cos \alpha}{F' \frac{\rho}{2} v_m^2}$$

in which

$$W_R = W_{tot} - A \tan \alpha \quad \text{and} \quad R = \frac{v_m \, l'}{\nu}$$

we find that the values corresponding to a single planing surface are approximately constant and become greater, the smaller the value of the mean Reynolds Number. In judging the scattering about the given mean value, it must be taken into consideration that all the scattering is due to the frictional resistance used in the formula, so that it seems to be by so much the greater, the greater the deduction $W_f = A \tan \alpha$ from the total resistance is, i.e., at greater angles. Moreover, the wetted length l' occurs as an experimental value, and a slight error in reading it may assume considerable importance for the smallest wetted lengths.

In appraising this, it can be asserted that a conjecture voiced in certain quarters has not been borne out. This was that measurements made in this range of Reynolds Numbers might lead to incorrect results, because, immune to external influence, different conditions of the boundary layer might appear, according to whether a test run were made in perfectly still water or in slightly rough water. (Reference 2.) Since the individual test runs were made partly in perfectly still water (at the beginning of the runs and after waits) and partly in rough water, the good "lie" of the experimental points shows clearly that, for the time being, there existed only a single stable form of boundary layer. In order to determine whether the friction coefficients, which lie below the curve for the turbulent boundary layer, would fall on this curve, if the leading edge of the wetted area were smoother, the following successive tests were made on surface 3 for comparison with run 26. In this run the surface had a wetted length of 250 mm (9.84 in.). The surface was first roughened over a belt of 20 mm (0.79 in.) in width, i.e., from 230 to 250 mm (9.05 to 9.84 in.) in its length; then over a belt 40 mm (1.57 in.) in width, from 210 to 250 mm (8.27 to 9.84 in.) in its length; and lastly over a belt 80 mm (3.15 in.) in width, from 170 to 250 mm (6.7 to 9.84 in.) in its length. The results were as follows:

The first 8 per cent roughening caused no increase in the resistance; the second 16 per cent roughening caused an increase of about 12.3 per cent; and the third 32 per cent roughening, an increase of 31 per cent. This shows that a slight roughening caused no change in the condition of the boundary layer and that only extensive roughening of the surface caused an increase in the coefficients.

The coefficients of different surfaces differ from one another for the same Reynolds Number, which is attributable to the fact that the load and the angle of trim of the surfaces and hence the pressure increment affecting the boundary layer are dissimilar at the leading edge.

In Figure 5 the surface coefficient F'/b^2 and the moment coefficient M/Ab are plotted against α. For both coefficients no systematic deviation from a mean curve can be established, so that it can be said that in the investigated region there is similarity of the wetted areas, similarity of the moments at the same angle of trim, and consequently consistent similarity of pressure distribution.

II. SCALE TESTS WITH FLOATS

In the above-described series of tests the investigation was limited to a single point of the pure planing condition. It did not include the region of the maximum resistance of a float, which is of special importance in the investigation of the float system. It is also necessary to explain the influence of the part of the float behind the step, which during the larger part of the starting run is in the spray and therefore considerably increases the frictional resistance.

For this purpose the scale experiments with floats, which were begun by the D.V.L. (Deutsche Versuchsanstalt für Luftfahrt) in the H.S.V.A. in 1929, were completed by the H.S.V.A. according to a new experimental program arranged with a view to reducing the cost of the experiments.

These experiments began with a towing test of a single full-scale float of the type H.S. 1 H with $G = \frac{1}{2}$ the gross weight = 1,200 pounds, which was made in the towing tank with freedom to trim and with the weight on the water reduced as the square of the speed up to the maximum speed of 9.5 m/s (31.2 ft./sec.). The applied lift was $E = G(v^2/v_s^2)$, in which v_s = take-off speed = 23.33 m/s (76.54 ft./sec.). No dependence of the applied lift on the angle of attack was introduced, since it was not necessary in a study of scale effect. The position of the c.g. with respect to height and length was determined, as likewise the point of application of the pull. The resistance and angle of trim were measured and also, at one speed, the extent of the spray in a definite plane at right angles to the float. As further scales, λ = 3, 6, 9, and 12 were chosen.

The tests were made with all of the model floats under like experimental conditions on the basis of the Froude model law. This series of tests showed the effect of the scale on the resistance, angle of trim and spray formation at the same moment of trim.

Two or three test curves were plotted in the region of the maximum resistance, either by bringing the models to the same angle of trim as the full-scale float by varying the moment, or by establishing the dependence of the resistance and moment on the angle of trim by towing with two other constant locations of the c.g., so that the corresponding values for the angle of trim of the full-scale float could be determined by interpolation.

As a result of this series of experiments we obtain the scale effect on resistance and moment at the same angle of trim, i.e., the real scale effect from changing the frictional coefficients, if it can be assumed that, at the same angle of trim, the planing surfaces under pressure and also the additional areas of the stern wet by the spray are similar.

Set-Up

On the full-scale float there was mounted a strong channel section which had to absorb all the forces. To a cross arm were attached lines leading to the dynamometer and to counterweights simulating the wing lift. On the U rail ran a sliding weight of 100 kg (220 lb.), by means of which it was possible to shift the c.g. of the float. The float was weighted with ballast bags, which were placed inside for stability. The full-scale float and the models were all trimmed alike, as all had the c.g. in the same relative position with respect to the height and length. The tests were made with the models as with the planing surfaces, but with apparatus adapted to the forces to be measured.

Results

In Figures 6 and 7 the resistance and angle of trim of the full-scale float are plotted against v. With the original location of the c.g. the tests could be carried only to $v = 8.75$ m/s (28.7 ft./sec.), since the angle of trim became too large beyond this point. A second test was therefore made with an additional nose-heavy moment, at which even the maximum was fully included and could be perfectly measured.

In the diagrams, moreover, the curves for the resistance and angle of trim of the individual models are plotted with $W = w\,\lambda^3$. The comparison of the results shows that, with the same moment, the maximum resistance given by the expression $W = w\,\lambda^3$ is too high by

3.5% for $\lambda = 3$,	10.5% for $\lambda = 9$,
6% " $\lambda = 6$,	21.5% " $\lambda = 12$.

The angles of trim of the models at the maximum are somewhat more than 1° lower than the angle of trim of the full-scale float. The maximums experience a slight displacement toward higher speeds for smaller scales. This corresponds to the opinion that the relatively greater viscosity of the water with the small model causes the separation of the water to take place somewhat later.

In Figure 7, moreover, the resistances are plotted for equal angles of trim, starting with the angle of trim of the full-scale float. We obtain a resistance increment of

8.5% for $\lambda = 3$,	17% for $\lambda = 9$,
10.5% " $\lambda = 6$,	25% " $\lambda = 12$.

In Figure 8 the percentage of increase in the resistance is plotted against λ. The value $\lambda = 3$ at $\alpha =$ constant falls completely off the curve, since the resistance changed greatly with α, because of a change in the angle of trim which was unimportant in itself.

Before reaching the maximum resistance, the agreement is practically perfect so long as the float has not reached the planing stage. A regular shift of the resistance and angle-of-trim curve first begins with the transition from the floating to the planing stage. In the planing stage beyond the maximum the tests show that for the same moment the angle of trim increases as smaller models are used (otherwise than in the results of the planing-surface tests, which exhibited no definite tendency), the shift over the whole range being nearly constant. The mean angular difference between two of the chosen scales was about 1°. If we extrapolate with this value on the angle-of-trim curve for the full-scale float, we obtain the following approximate changes in the angle of trim.

Scale	Angle-of-trim increment in the planing state
$\lambda = 3$	1°
$\lambda = 6$	2°
$\lambda = 9$	3°
$\lambda = 12$	4°

The resistance increment is also approximately constant for all scales over the planing range investigated, so that the percentage increment increases as the speed is increased. Especially noticeable is the great increase of the resistance in the transition from $\lambda = 9$ to $\lambda = 12$. The influence of the increased resistance on the experimentally determined take-off time, without correction for friction varies according to the magnitude of the available excess propeller thrust. The take-off time is

$$t = \frac{G}{g} \int_{o} \frac{1}{S - W} \, dv^*$$

If the resistance curve of the full-scale float is extrapolated from the experimentally determined towing curves, the percentage increase in the take-off time would amount to

	$\lambda = 3$ %	$\lambda = 6$ %	$\lambda = 9$ %	$\lambda = 12$ %
20% maximum excess thrust	3.8	10.9	26	146
40% " " "	3.0	6.0	12	34

*G = gross weight,
S = propeller thrust,
W = total resistance of water and air,
v_s = take-off speed.

Scale Effect on Formation of Spray

In Figure 9 the contours of the spray are plotted, as measured on the full-scale float and on the individual models converted to full scale. The measurements were made on the full-scale float for $v = 8.75$ m/s (28.7 ft./sec.) in the transverse plane 0.5 m (1.64 ft.) in front of the step and on the models at the corresponding speeds and at the proportional distances in front of the step. The maximum variation in the angle of trim was 0.5°.

In evaluating the test it must be borne in mind that there is no sharp transition from the area covered by the spray to the area that is free from the spray. During a test therefore the measuring pointers are set as uniformly as possible at the upper contour of the main body of the spray.

The measurements plainly show that the relative height of the spray decreases as the size of the model is reduced, which can be explained, with constant surface tension, by the formation of relatively larger drops. All float appendages in the lateral spray, such as auxiliary floats, the wheels of amphibians, the sponsons of flying boats, etc., are therefore too favorably measured when the scale of the model is too small. The same statement applies to twin floats, if they strongly spray each other. Figures 10 and 11 are comparative photographs of the models at $\lambda = 3$ and $\lambda = 12$, respectively.

Choice of the Scale

If conclusions are to be drawn from these data regarding the choice of the scale, it should first be noted that the scale effect varies as a frictional effect with the size of the wetted surfaces and that, e.g., the size of the wetted surfaces depends considerably on the bottom angle, so that these results can serve only as a basis for limiting the scale. (Reference 3.)

The first requisite is that the nature of the flow shall be similar for the model and for the full-scale float. It was found that, with planing surfaces 5 and 6, even at medium angles of trim, the water still adhered to the lateral surfaces, although with wider surfaces the pure planing phase had already begun.

If $c_B = \frac{A}{b^2 \frac{\rho}{2} v^2}$, the nondimensional load coefficient which equals 0.109 for all gliding surfaces, then the same load coefficient for the float is reached at $v = 12.81$ m/s (42.03 ft./sec.), since $\frac{G - E}{b^2 \frac{\rho}{2} v^2}$, when $v = 12.81$ m/s and $E = G \frac{v^2}{v_s^2} = 362$ kg (798 lb.). Here the float also is in the pure planing phase. If we assume a planing surface of the width of the float, 0.957 m (3.14 ft.), as full-scale, for which the load would be 586 kg (1,292 lb.) at $v = 10.7$ m/s (35.1 ft./sec.), then surface 5 corresponds to $\lambda = 9.57$ and surface 6 to $\lambda = 12.75$. The planing-surface tests show therefore that even below $\lambda \cong 9$ the form of flow is partially dissimilar. The especially great increase in resistance in the float tests between $\lambda = 9$ and 12 confirms this conclusion. In order to determine whether this is also the case with a greater load, e.g., for the load $G - E = 948$ kg (2,090 lb.) corresponding to the full-scale float at 10.7 m/s (35.1 ft./sec.), a check test was made with the planing surface 6 with a similar load $\frac{(G - E)}{12.75^3} = 0.455$ kg (1 lb.) and corresponding speed, for the purpose of observing the flow. In this test it was found that also up to high angles, the water adhered completely to the lateral surfaces. It is particularly noticeable that no real spray is formed as with the other surfaces, but next to the planing surface only waves with smooth surfaces whose elevation above the water level is naturally lower than the top of the spray of a full-scale float. Thus the result of the spray measurement of the full-scale float is confirmed.

After it has been shown that no conversion taking account of frictional resistances can be made, a second requirement is made that the scale should be such that, even disregarding the scale effect, results will be obtained which will differ from the true values only within a conversion accuracy common in model tests. The float tests show that, with a scale $\lambda = 4$, the maximum resistance is exceeded by less than 5 per cent, the angle of trim at the maximum and in the planing condition differs by about 1°, and the take-off time is too high by 4 to 5 per cent at 20 to 40 per cent excess thrust. For this scale, the formation of the spray is practically the same as for the full-scale float, so that all appendages are wet similarly.

$\lambda = 4$ can therefore be regarded as the proper scale for testing floats of this size. In testing larger objects, like flying boats, it is to be considered, in choosing the scale, that, with the enlargement of the planing surfaces, no further great change occurs in the frictional coefficients, as shown by Figures 3 and 4. If, with respect to the load, the single float of $G/2 = 1{,}200$ kg (2,646 lb.) be regarded as the model of a flying boat of (e.g.) 9,600 kg (21,164 lb.) gross weight, an enlargement factor $\lambda' = \sqrt[3]{\frac{9600}{1200}} = 2$ is obtained, i.e., the model of the flying boat at the scale $\lambda \lambda' = 4 \times 2 = 8$ will yield approximately the same accuracy of conversion as the float model at the scale $\lambda = 4$. A somewhat larger scale, about $\lambda = 6$ is preferable even here, provided the experimental apparatus permits the testing of models of this size. The new towing tank of the H.S.V.A. is equipped for testing such large float models (Werft-Reederei-Hafen, 1931, No. 11).

Discussion

H. Wagner called attention to the fact that, according to theoretical considerations, a spray must be thrown forward by the planing surface and that the friction of this spray on the part of the bottom exposed to it might be as great as the friction on the rest of the bottom.

W. Sottorf replied that the spray as described by Wagner, did not form on the forward surface, and that only with a medium V-shaped bottom was an adhering spray thrown off laterally toward the front.

H. Wagner stated that, mathematically, a considerable portion of the resistance is contained in the energy of the spray and that its failure to appear in the test was perhaps due to the atomization of the spray. The spray corresponds (in the language of the wing theory) to the loss of suction of the planing surface as compared with the wing.

G. Weinblum had calculated the Sottorf tests and had found that the wave resistance calculated according to the center-of-pressure theory (Hogner integral) agreed with the resistance measured in the tests up to about 75 per cent. He thought that the essential part of the resistance was given by the center-of-pressure theory.

H. Wagner called attention to the fact that the center-of-pressure theory assumed an infinitely small angle of trim. In uneven pressure reductions at the margin of the planing surface, however, the angle of trim becomes finite, and spray is formed. This mathematically determined phenomenon is not included in the center-of-pressure theory and therefore yields the correct planing resistance only in the few cases where, corresponding to the shape of the plate, the pressure distribution is uniform at the leading edge.

G. Weinblum was of the opinion that the center-of-pressure theory gave the approximately correct resistance, even for uneven pressure distribution.

H. Wagner stated that, as regards his calculation, the unevenness of the pressure at the leading edge assumed the character of a force concentrated along the edge and that, therefore, the center-of-pressure method, as regards the resistance, does not lead directly to correct results. He stated that, among other things, he had discussed the resistance of planing surfaces in an article soon to be published (Z.f.a.M.M., August, 1932). In the limiting case of high speed or negligible acceleration due to gravity, it was found that twice the resistance of a planing surface is equal to the resistance of a similarly shaped wing minus the suction force at the leading edge of the wing. The increase in the resistance from the subtraction of the suction force corresponds to the energy of the spray. For a smooth planing surface of infinite span the resistance is therefore equal to the lifting force times the angle of trim of the planing surface. In this limiting case, however, the center-of-pressure theory yields zero resistance.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics

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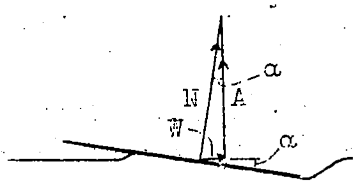
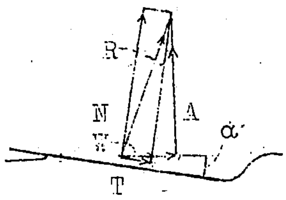
3. Herrmann, H., Kempf, G., and Kloess, H.: Tank Tests of Twin Seaplane Floats. T.M. No. 486, N.A.C.A., 1928.

   Herrmann, H.: Seaplane Floats and Hulls. T.M. No. 426, N.A.C.A., 1927. Part I.

   Herrmann, H.: Seaplane Floats and Hulls. T.M. No. 427, N.A.C.A., 1927. Part II.



(a)
Forces on flat planing surface with nonviscous fluid.



(b)
Forces on flat planing surface with viscous fluid.

Figure 1.

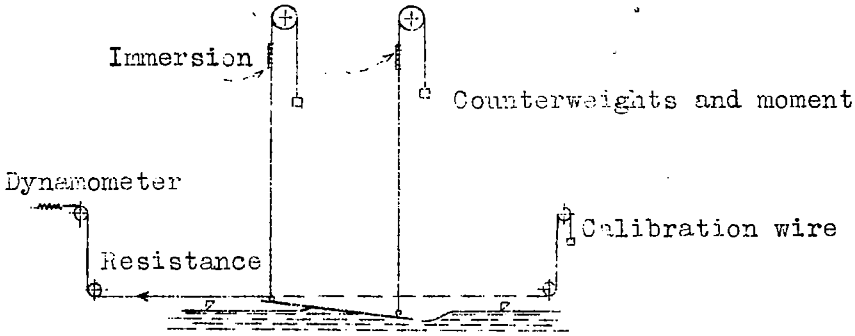
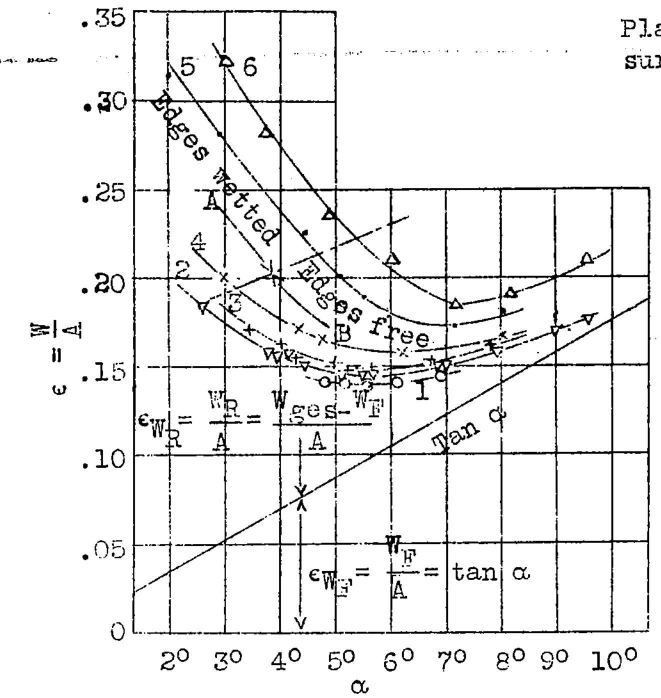


Figure 2. - Diagram of test set-up.

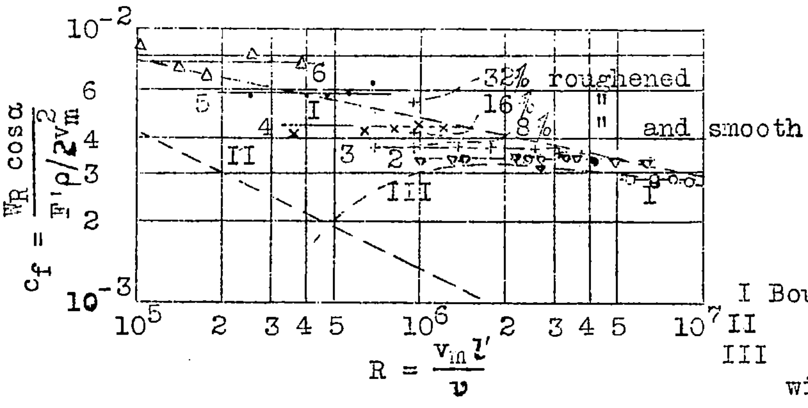


Planing surface		λ	b_m	A_{kg}	$\frac{v_m}{sec}$
1	o	1	.600	144.000	8.48
2	▿	2	.300	18.000	6.00
3	+	2.666	.225	7.600	5.20
4	×	4	.150	2.250	4.24
5	•	6	.100	.660	3.46
6	▵	8	.075	.281	3.00

A No pure planing condition

B Pure planing condition

Figure 3. - Planing number ε plotted against angle of trim α.



Planing surface

o	1,	b = .600 m
▿	2,	b = .300 "
+	3,	b = .225 "
×	4,	b = .150 "
•	5,	b = .100 "
▵	6,	b = .075 "

I Boundary layer turbulent

II " " laminar

III " " turbulent with laminar approach.

Figure 4. - Coefficient of frictional resistance plotted against Reynolds Number for flat planing surfaces.

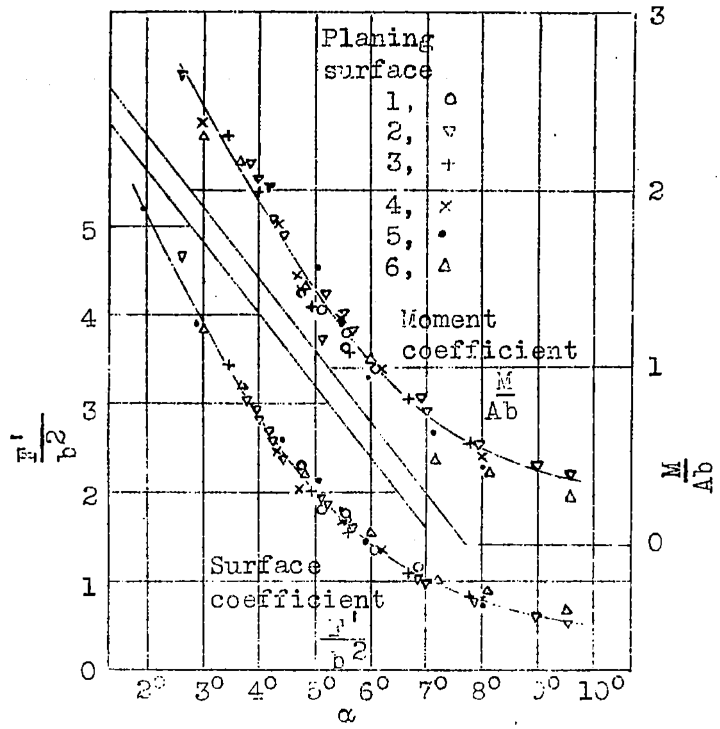


Figure 5.- Surface coefficient F'/b^2 and moment coefficient M/Ab plotted against α.

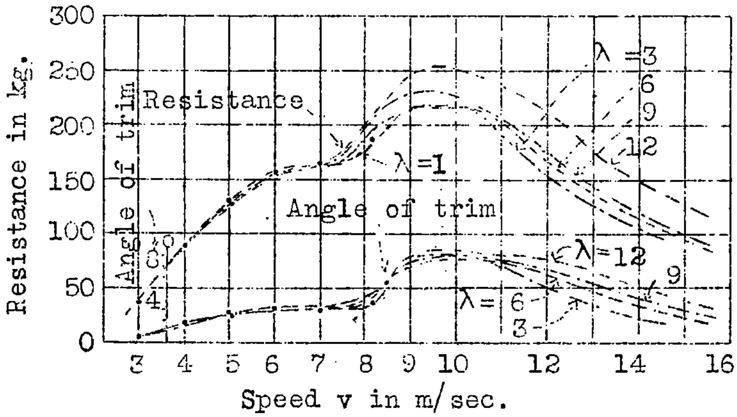


Figure 6.- Resistance and angle of trim for M_1 = constant. All resistances and angles of trim converted to full scale for λ = 3,6,9 and 12 with the same moment of trim.

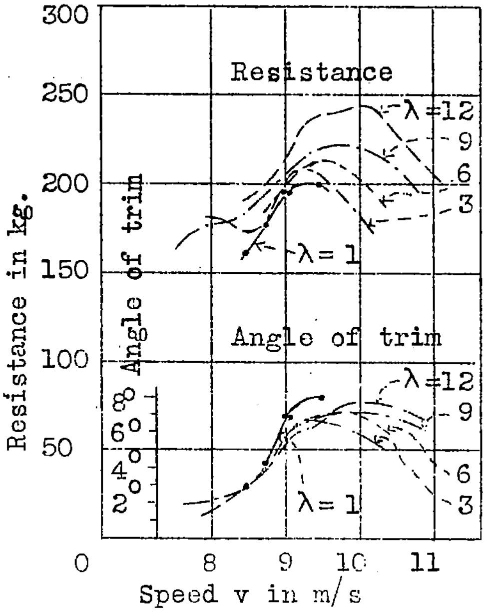


Figure 7a.- Resistance and angle of trim of full-scale float for M_2 = constant, along with resistances and angles of attack converted to full scale for λ,=,3,6,9,12 with same moment.

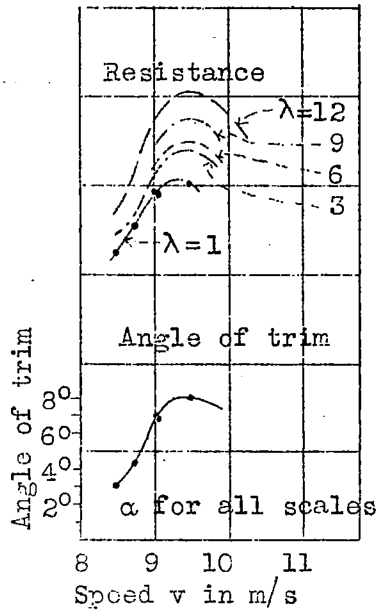


Figure 7b.- Resistance of models at same angle of trim as full-scale float.

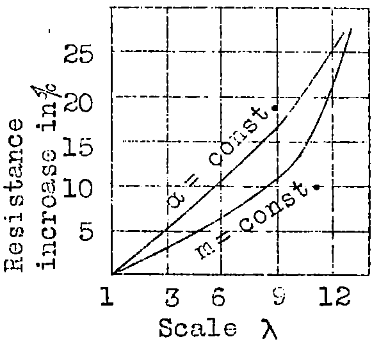


Figure 8.- Percentage increase in resistance at maximum plotted against scale.

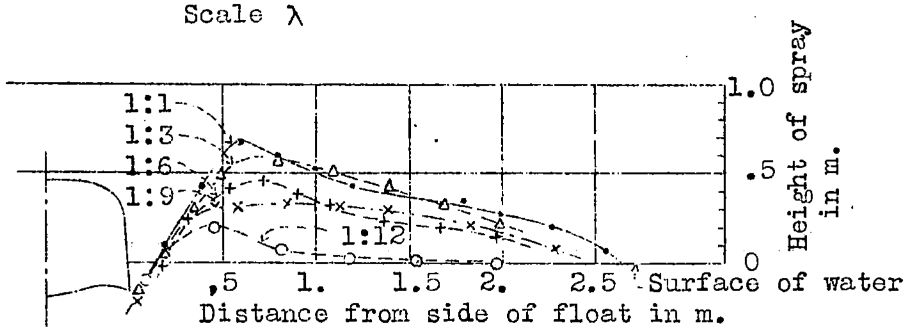


Figure 9.- Spray formation measured on full-scale float 0.5 m (1.64 ft.) in front of step at v = 8.75 m/s (28.7 ft./sec.) and on all models at same distance and at corresponding speeds, converted to full-scale.

Figure 10.- $\lambda = 3$, $\alpha = 6^{\circ}$, $v = 5.5$ m/s (18.04 ft./sec.) corresponding to $V = 9.5$ m/s (31.17 ft./sec.)

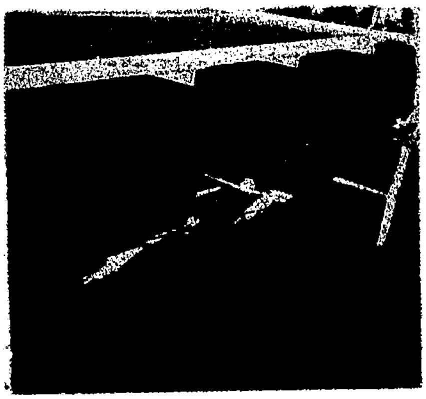


Figure 11.- $\lambda = 12$, $\alpha = 6^{\circ}$, $v = 2.75$ m/s (9.02 ft./sec.) corresponding to $V = 9.5$ m/s (31.17 ft./sec.)

17.0

22 $\frac{1}{2}$

31

36

6

31
22
9